A survey of pathogens and metazoan parasites on wild sea trout (*Salmo trutta*) in Scottish waters

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In all, 300 wild sea trout were sampled from three east coast and two west coast sites around Scotland over a 3-year period to establish the prevalence and the abundance of bacteria, viruses, and ecto- and endoparasites. No bacterial pathogens were isolated from any fish. One fish tested positive for viral pathogens (infectious pancreatic necrosis virus). The viral agent syncytium, resulting from aquareovirus infection, was found in four fish from the east coast. The parasitic fauna consisted of three classes of ectoparasite, Monogenea, Isopoda, and Copepoda, and four classes of endoparasite, Cestoda, Digenea, Nematoda, and Acanthocephala. Sea trout from the east coast sites were larger than those from the west coast. The abundance of *Lepeophtheirus salmonis*, *Hysterothylacium aduncum*, and *Anisakis* sp. was significantly greater at the east coast sites. The only parasite found in significantly greater numbers at a west coast site was *Pomphorhynchus laevis*.

Keywords: disease, parasites, Scotland, sea lice, sea trout.

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Introduction

Sea trout (*Salmo trutta*) are anadromous fish that migrate to the sea and return to freshwater to spawn. They generally remain close to the coast during their marine phases and may return to freshwater to spawn more frequently than Atlantic salmon (*S. salar*; Laird and Needham, 1991; Gargan *et al.*, 2006).

Stocks of sea trout have declined substantially on the west coast of Scotland and Ireland over the past 20 years, likely as a consequence of an increase in marine mortality coupled with possible interaction with sea lice arising from aquaculture (Butler, 2002; Penston *et al.*, 2004). Similar declines have also been observed in areas free of marine finfish aquaculture, such as southwest of Scotland, England, and Wales (McGeorge and Sommerville, 1996). The decline in the numbers of sea trout is not due to a single cause, but is multifactorial in nature (Costelloe *et al.*, 1998). For example, both sea surface temperature and the abundance of pathogenic organisms may impact the marine phase of sea trout, because both have been linked to the decline in the condition of returning Atlantic salmon over the past decade (Todd *et al.*, 2008).

Previous surveys of sea trout have focused on the numbers of sea trout in different locations (Calderwood, 1930; Nall, 1930; Anon., 2003). Although some surveys have reported the presence of ectoparasites on wild sea trout (MacKenzie *et al.*, 1998; Schram *et al.*, 1998; Todd *et al.*, 2000; Urquhart *et al.*, 2008), no studies have described the overall health status of wild sea trout populations.

This study describes a survey to determine the presence of viral and bacterial agents and the numbers of metazoan parasites on wild sea trout around Scotland. Wild sea trout were sampled from five locations, two on the west coast and three on the east coast of Scotland, between 2005 and 2007. The trout were examined for the presence of fish pathogens, and differences in parasite abundance between parasite species, locations, and years were investigated.

Material and methods

Wild sea trout sampling sites

The sampling sites are shown in Figure 1. A total of 90 wild sea trout was obtained from bagnets near the North Esk (NGR NO 742 625) on the Scottish east coast in May and June of 2005, 2006, and 2007, as described in Urquhart *et al.* (2008). Another 58 wild sea trout were obtained by sweepnetting in the Upper Forth estuary near Alloa (NGR NS 831 945) on the Scottish east coast between May and August of 2006 and 2007. In all, 32 wild sea trout were caught by gillnetting from Stonehaven Bay (NGR NO 882 856) in July 2006. Fish could not be sampled from Stonehaven Bay in other years for conservation reasons. On the Scottish west coast, gillnetting was used to capture 60 wild sea trout from the River Annan (NGR NY 206 672) in July and August of 2006 and 2007, and 60 more from the River Carron (NGR NG 925 425) between August and December of 2006 and 2007. Fish were euthanized by concussion in the field, and samples were taken for virological and bacterial analysis, as

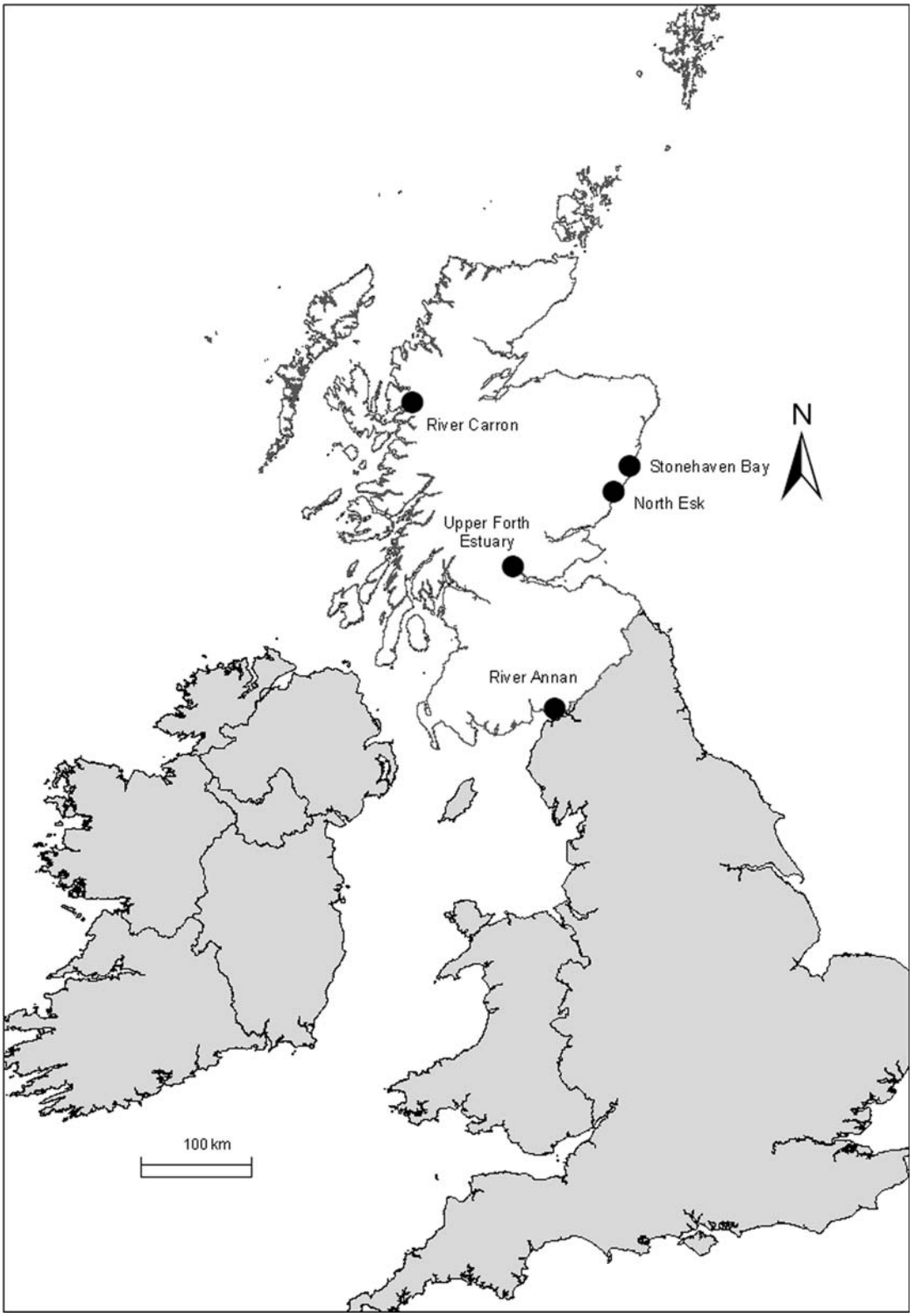

Figure 1. Map showing the sampling sites around Scotland.

described below. Fish were screened visually (by eye) for ectoparasites, and scales were removed from each fish for age determination (Table 1). Fish were then placed into individual labelled polythene bags and transported to the laboratory at 4°C. At the laboratory, length and weight of each fish were recorded (Table 1), body surface, gills, and fins were examined for ectoparasites, and fish were frozen at −20°C until further screening was carried out for the presence of endoparasites.

Table 1. Number of sea trout, median length, weight, and sea age (with ranges in parenthesis) for each site and year.

Area	Year	Number of fish	Length (cm)	Weight (kg)	Sea age
North Esk	2005	30	–	1.11 (0.73, 2.13)	–
	2006	30	44.0 (38.0, 49.0)	1.10 (0.67, 1.91)	1 (1, 1)
	2007	28	45.8 (37.8, 64.9)	1.06 (0.66, 2.42)	1 (1, 2)
Upper Forth estuary	2006	32	46.6 (29.1, 62.3)	1.09 (0.34, 2.06)	1 (1, 2)
	2007	30	45.7 (40.3, 56.5)	1.21 (0.88, 2.08)	1 (1, 1)
Stonehaven Bay	2006	30	48.0 (28.0, 66.0)	1.16 (0.23, 2.87)	1 (1, 2)
River Carron	2006	30	22.1 (19.7, 29.0)	0.16 (0.08, 0.31)	3 (2, 4)
	2007	30	30.8 (18.2, 37.2)	0.31 (0.05, 0.53)	2 (1, 3)
River Annan	2006	30	23.8 (19.5, 37.6)	0.16 (0.10, 0.75)	2 (0, 3)
	2007	30	25.7 (22.3, 28.6)	0.18 (0.14, 0.28)	–

Length was not recorded at the North Esk in 2005. Age was not recorded at the North Esk in 2005 or the River Annan in 2007, and only 12 fish were aged at the River Carron in 2006.

Screening of sea trout for viral and bacterial pathogens

All fish sampled were screened for the presence of viral disease agents, including infectious salmon anaemia virus, viral haemorrhagic septicaemia virus, infectious haematopoietic necrosis virus, salmonid alphavirus, and infectious pancreatic necrosis virus (IPNV), using the following cell lines: TO, bluegill (*Lepomis macrochirus*) fry (BF_2), fathead minnow (*Pimephales promelas*) (FHM), and Chinook salmon (*Oncorhynchus tschawytscha*) embryo-214 (CHSE) for the last two pathogens, respectively. Samples of kidney, liver, spleen, brain, and heart were taken into transport medium [L-15 medium supplemented with 10% newborn calf serum (Biowhittaker; Life Technologies), 200 U ml^{-1} penicillin–streptomycin (Life Technologies), 1 mg ml^{-1} gentamycin (Life Technologies), 200 U ml^{-1} polymixin B sulphate (Sigma), and adjusted to a pH of 7.4] and processed by standard virology tissue-culture methods (Dannevig *et al.*, 1995; EU, 2001; Smail *et al.*, 2003).

Samples of anterior kidney were taken and inoculated onto each of Tryptone Soya Agar (Oxoid), Tryptone Soya Agar supplemented with 2% w/v sodium chloride (NaCl, Oxoid, Sigma), Mueller–Hinton agar supplemented with 2% w/v cysteine (Oxoid, Sigma), and Anacker and Ordal agar (Oxoid) using a sterile, disposable inoculating loop and screened for the presence of pathogenic bacteria by standard bacterial-culture methods (Holt *et al.*, 1994).

Screening of sea trout for metazoan parasites

A visual assessment of the external surface of each fish was carried out in the field to determine ectoparasite loads, as described by Pert *et al.* (2009). Briefly, any visible ectoparasites observed at the time of sampling were recorded, and their position on the host was noted prior to transfer into 70% ethanol for further identification under a light microscope. Whole fish were then frozen in individual bags prior to further analysis.

Fish were defrosted, fins and gills removed with scissors, and fish were placed into separate Petri dishes, irrigated with water, and examined under a dissecting microscope (Wild Heerbrugg) at up to ×400 final magnification.

To determine endoparasite loads, the lower jaw, operculum, and eyes were removed and placed into separate Petri dishes before the upper surface of the mouth was examined visually. The visceral cavity was opened longitudinally along the ventral surface, followed by perpendicular anterior and posterior cuts through the peritoneum, and the liver, spleen, gonads, and gut were removed and placed on a metal tray. The gut was divided into stomach, pyloric caeca, anterior intestine, mid-intestine, and rectum before being placed into separate Petri dishes and examined under a dissecting microscope (Wild Heerbrugg) at up to ×400 final magnification.

Each section of the alimentary tract was opened longitudinally with a scalpel and examined initially for parasites *in situ*. The contents were scraped into a Petri dish with a little water, then examined. Heart and kidney were removed and placed into individual Petri dishes, cut into sections, and examined. Any parasites found during the sampling process were preserved by placing them into a 7-ml bijou tube (Greiner) containing 70% ethanol (Sigma) before morphological examination and identification to species level using Moravec (2004) binomial keys.

Data analysis

Differences in parasite abundance between species, areas, and years were investigated using hierarchical generalized linear models (Lee *et al.*, 2006). These allow the observed abundance values to be distributed with Poisson errors, the standard distribution for count data (McCullagh and Nelder, 1989), augmented by a variance component allowing for additional fish-to-fish variation (overdispersion). Hierarchical generalized linear models extend the more familiar generalized linear-mixed models (McCulloch and Searle, 2001); they can have random effects (such as the fish-to-fish variation) with distributions other than the normal distribution, tend to give less biased estimates, and have better inferential tools (Lee *et al.*, 2006).

Let z_{pf} be the count of parasite species p on fish f. It was assumed that z_{pf} has a Poisson distribution with mean $\mu_p\varepsilon_{pf}$, where μ_p is the mean abundance of parasite species p and ε_{pf} is a gamma-distributed random effect with mean 1 and s.d. σ_p. Within-fish correlations among the random effects were negligible and ignored. The mean abundance values were related to the explanatory variables, parasite species, area, and year, through a log link. First, a full model, log mean abundance ~ parasite species × area × year, was fitted to the data. The three explanatory variables are all categorical, and the full model includes all their main effects and interactions. The model was then simplified in a backwards stepwise procedure on the basis of Akaike's Information Criterion (AIC) defined as: AIC = −2 × log-likelihood + 2 × number of parameters in the mean model. The model with the fewest parameters within two units of the minimum AIC was considered the best of the competing models (Jones, 1993). All p-values presented in the text are based on likelihood-ratio tests, because these are more reliable than

comparing parameter estimates with their standard errors. Values of p for pairwise comparisons between sites were corrected for the number of comparisons. All statistical analyses were carried out using GenStat for Windows, 12th edition (Payne *et al*., 2009).

Results

In all, 300 wild sea trout were captured for study. On the east coast, 96% were first-sea-winter (1SW) fish. On the west coast, the fish ranged from finnock (sea trout returning to freshwater a few months after migrating as smolts) to fourth-sea-winter (4SW) fish, with a median sea age of 2 years. The fish from the east coast were typically larger than those from the west coast (Table 1).

All fish tested negative for bacterial pathogens. Only one fish from the River Carron tested positive for the viral pathogen IPNV during 2007. Two fish from Stonehaven Bay (2006) and two fish from the Upper Forth estuary (2007) tested positive for syncytia on the Chinook salmon embryo (CHSE-214) cell line. The causative agent of the syncytia was aquareovirus (Murray, 2009).

The prevalence and the abundance of all metazoan parasites observed in this study are summarized in Tables 2 and 3. Metazoan ectoparasites were found on 49% of the fish. These consisted of two species of Copepoda (*Lepeophtheirus salmonis* and *Caligus elongatus*) and one species of Isopoda (*Gnathia elongatus*), found only in the Upper Forth estuary in 2006. Totals of 9182 endoparasites and >2000 cysts were identified and classified as Cestoda, Digenea, Nematoda, and Acanthocephala (Table 4). For simplicity, the modelling of parasite abundance was restricted to the years 2006 and 2007 to the four sites that were sampled in both years (North Esk, Upper Forth estuary, River Carron, and River Annan) and to six parasite species found in sufficient numbers for analysis (the ectoparasites *L. salmonis* and *C. elongatus*, and the endoparasites *Anisakis* sp., *Hysterothylacium aduncum*, *Eubothrium* sp., and *Pomphorhynchus laevis*).

Parasite abundance was adequately described by the model: log mean abundance ~ area × parasite species + year × parasite species. Therefore, parasite abundance depended on area, although the relationship differed between species ($p < 0.0001$); i.e. there was an interaction between area and species. Area had a significant effect on the abundance of all six species (*Eubothrium* sp.: $p = 0.013$; all others: $p < 0.0001$; Figure 2). The abundance of *H. aduncum*, *Anisakis* sp., and *L. salmonis* was greater at the east coast sites ($p < 0.0001$ in all cases). The abundance of *C. elongatus* was greatest at North Esk ($p < 0.0001$), and there were no differences between the other three sites ($p > 0.05$). The abundance of *Eubothrium* sp. was greater in the Upper Forth estuary than in the River Annan ($p = 0.042$), whereas all other area comparisons were non-significant; and the abundance of *P. laevis* was greatest in the River Carron ($p < 0.0001$), with no differences between the other three sites ($p > 0.05$). Parasite abundance also depended on year, with the relationship differing between species ($p < 0.0001$). The abundance of *H. aduncum* was greater in 2007, whereas that of *P. laevis* was greater in 2006 ($p < 0.0001$ in both cases; Figure 3). The abundance of the other species did not differ significantly between years ($p > 0.05$). There was no interaction between area and year, so

Table 2. Observed prevalence (%) of ecto- and endoparasites for each sampling site and year.

	North Esk			Upper Forth estuary		Stonehaven Bay	River Carron		River Annan	
Taxon	**2005**	**2006**	**2007**	**2006**	**2007**	**2006**	**2006**	**2007**	**2006**	**2007**
Lepeophtheirus salmonis	100	93	87	29	60	84	–	3	23	10
Caligus elongatus	90	43	50	–	3	50	–	–	–	–
Discocotyle sagittata	17	–	–	–	–	–	–	–	–	–
Gnathia elongatus	–	–	–	4	–	–	–	–	–	–
Eubothrium sp.	23	17	13	18	20		3	10	3	7
Diphyllobothrium sp. (larvae)	23	–	–	–	10	–	–	–	–	–
Cestode	7	–	–	7	–	3	–	–	3	–
Bucephalus polymorphus	–	–	–	–	–	–	–	–	3	–
Cryptocotyle lingua	–	–	–	–	–	–	3	–	3	–
Hemiurus sp.	3	–	–	–	–	–	–	–	–	–
Hemiurus communis	–	3	–	–	–	–	–	–	–	–
Podocotyle atamon	23	–	–	–	10	–	–	–	–	–
Diplostomum sp.	10	–	–	–		–	–	–	–	–
Anisakis sp.	40	83	100	96	100	69	3	7	–	–
Hysterothylacium aduncum	60	70	77	61	87	12	–	10	3	–
Hysterothylacium fabri	–	–	3	–	10	–	–	3	–	–
Contraceacum sp.	–	13	10	14	27	3	3	–	–	–
Pseudoterranova	–	–	–	11	3	–	–	–	–	–
Pseudoterranova decipiens	–	13	3	4	3	12	–	–	–	–
Cucullanus cirratus	–	–	–	4		3	–	–	–	–
Cucullanus truttae	13	–	–	–	17	–	–	–	–	–
Cystidicoloides ephemeridarum	–	–	–	–	–	3	–	–	–	–
Capillaria sp.	17	–	–	–	–	–	–	–	–	–
Pomphorhynchus laevis	–	–	–	–	–	–	37	17	7	–
Acanthocephalus anguillae	–	3	–	–	–	–	–	–	–	–
Neoechinorhynchus	–	–	–	–	3	–	–	–	–	–
Cysts	–	3	–	–	–	–	–	–	–	–

Blank cells indicate zero prevalence.

Table 3. Sample mean abundance of endo- and ectoparasites (with standard errors in parenthesis) for each sampling site and year.

	North Esk			Upper Forth estuary		Stonehaven Bay	River Carron		River Annan	
Taxon	**2005**	**2006**	**2007**	**2006**	**2007**	**2006**	**2006**	**2007**	**2006**	**2007**
Lepeophtheirus salmonis	7.87 (1.02)	6.07 (0.72)	3.40 (0.46)	0.82 (0.32)	1.17 (0.25)	3.03 (0.41)		0.03 (0.03)	0.37 (0.07)	0.10 (0.06)
Caligus elongatus	8.56 (1.88)	1.47 (0.28)	0.86 (0.19)		0.03 (0.03)	1.06 (0.27)				
Discocotyle sagittata	0.20 (0.09)									
Gnathia elongatus				0.04 (0.04)						
Eubothrium sp.	0.37 (0.13)	0.17 (0.07)	0.20 (0.10)	0.32 (0.16)	0.30 (0.13)		0.03 (0.03)	0.10 (0.06)	0.03 (0.03)	0.07 (0.05)
Diphyllobothrium sp. (larvae)	0.43 (0.16)				0.23 (0.17)					
Cestode	0.10 (0.07)			0.07 (0.05)		0.03 (0.03)			0.03 (0.03)	
Bucephalus polymorphus									0.03 (0.03)	
Cryptocotyle lingua							0.10 (0.10)		0.23 (0.23)	
Hemiurus sp.	0.07 (0.07)									
Hemiurus communis		0.03 (0.03)								
Podocotyle atamon	0.77 (0.33)				0.23 (0.13)					
Diplostomum sp.	0.40 (0.27)									
Anisakis sp.	1.17 (0.80)	9.5 (1.87)	22.47 (5.69)	43.00 (10.55)	27.23 (5.64)	5.91 (1.23)	0.03 (0.03)	0.07 (0.05)		
Hysterothylacium aduncum	1.50 (0.35)	18.13 (6.92)	48.43 (19.87)	14.50 (4.70)	71.17 (32.06)	5.09 (4.78)		0.10 (0.06)	0.03 (0.03)	
Hysterothylacium fabri			0.17 (0.17)		0.86 (0.53)			0.03 (0.03)		
Contraceacum sp.		0.21 (0.11)	0.17 (0.11)	1.07 (0.68)	1.30 (0.60)	0.03 (0.03)	0.03 (0.03)			
Pseudoterranova				0.14 (0.08)	0.03 (0.03)					
Pseudoterranova decipiens		0.93 (0.55)	0.23 (0.23)	0.07 (0.07)	0.10 (0.10)	0.28 (0.14)				
Cucullanus cirratus				0.04 (0.04)		0.09 (0.09)				
Cucullanus truttae	0.23 (0.12)				0.70 (0.57)					
Cystidicoloides ephemeridarum						0.06 (0.06)				
Capillaria sp.	0.43 (0.18)									
Pomphorhynchus laevis							5.53 (2.81)	0.33 (0.15)	0.57 (0.50)	
Acanthocephalus anguillae		0.11 (0.10)								
Neoechinorhynchus					0.03 (0.03)					
Cysts		>66.7								

Blank cells indicate zero prevalence.

Table 4. Classification of ecto- and endoparasites.

Class	Species	Life cycle	Intermediate hosts*	Definitive host	Site of infection
Ectoparasites					
Copepoda	*Lepeophtheirus salmonis*	Direct	None	Salmonids	Body surface, in mouth, and under operculum
	Caligus elongatus	Direct	None	Marine fish	Skin and gills
Isopoda	*Gnathia elongatus*	Direct	None	Marine fish	Fish external surface and gills
Endoparasites					
Monogenea	*Discocotyle sagittata*	Direct	None	Salmonids	Gills
Cestoda	*Eubothrium* sp.	Indirect	(1) Copepod	Salmonids and cyprinids	Intestine, pyloric caeca
	Diphyllobothrium spp.	Indirect	(2) Molluscs[a] and fish sp.[b]	Salmonids, Osmerids	Encapsulated on stomach walls and intestine
Digenea	*Bucephalus polymorphus*	Indirect	(2) Mussels[a] and fish sp.[b]	Many fish species	Intestine
	Cryptocotyle lingua	Indirect	(2) Mollusc[a] and fish; mainly Gobiidae[b]	Fish-eating birds	Musculature
	Hemiurus communis	Indirect	(2) Copepodl[a] and planktonic invertebrates[b]	Many fish species	Stomach
	Podocotyle atamon	Indirect	(2) Mollusc[a] and crustaceans[b]	Many fish species	Intestine and pyloric caeca
	Diplostomum spp.	Indirect	(2) Mollusc[a] and fish sp. and amphibians[b]	Aquatic birds	Lens of eye
Nematoda	*Anisakis* sp.	Indirect	(2) Crustaceans[a] and fish or squid[b]	Seal/whale	Abdominal cavity and encysted in liver and some times musculature
	Hysterothylacium aduncum	Indirect	(1) Invertebrates and fish paratenic hosts	Migratory fish	Oesophagus, stomach, intestine, and pyloric caeca
	Hysterothylacium fabri	Direct	None	Migratory fish	In salmonids intestine; other species encapsulated in intestine, pyloric caeca, and gallbladder walls
	Contraceacum	Indirect	(2) Copepods[a] and fish[b]	Seal	Mainly liver and pyloric caeca.
	Pseudoterranova decipiens	Indirect	(2) Crustacean[a] and fish[b]	Seal	Internal organs of abdominal cavity
	Cucullanus cirratus	Direct	None	Marine fish and freshwater salmonids	Intestine
	Cucullanus truttae	Indirect	(1) Lamprey	Salmonids and lamprey	Pyloric caeca and anterior intestine; abdominal cavity of lampreys
	Cystidicoloides ephemeridarum	Indirect	(1) Mayflies	Salmonids	Stomach
	Capillaria sp.	Indirect	Unknown	Freshwater and migratory fish; Salmoniformes and Scorpaeniformes	Intestine
Acanthocephala	*Pomphorhynchus laevis*	Indirect	(1) Gammarids (paratenic small fish)	Many fresh- and brackish-water fish species	Intestine
	Acanthocephalus anguillae	Indirect	(1) Crustacean	Many fresh- and brackish-water fish species	Intestine
	Neoechinorhynchus spp.	Indirect	(1) Crustacean	Mainly cyprinids	Intestine

*Numbers in parenthesis indicate the number of intermediate hosts the parasite is known to have.
[a]The first intermediate host.
[b]The second intermediate host.

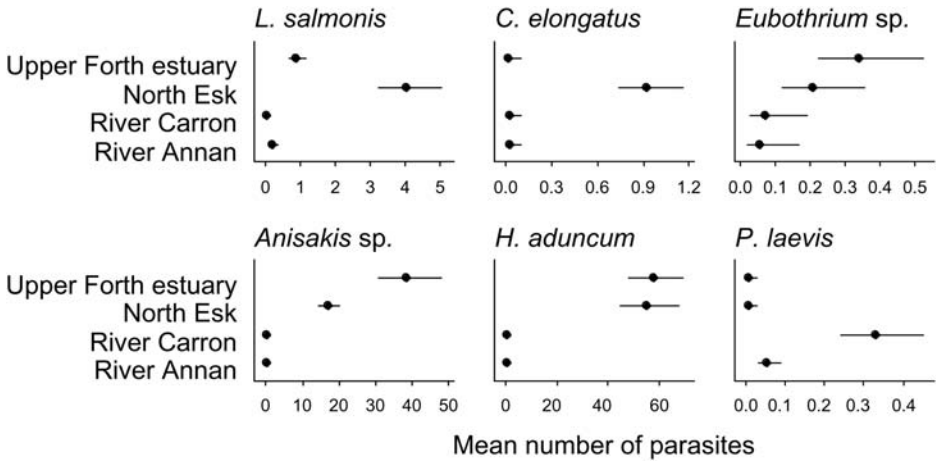

Figure 2. The effect of area on the abundance of each parasite species, with 95% confidence intervals. For easier interpretation, the area effects are centred on the estimated mean abundance at each site in 2007.

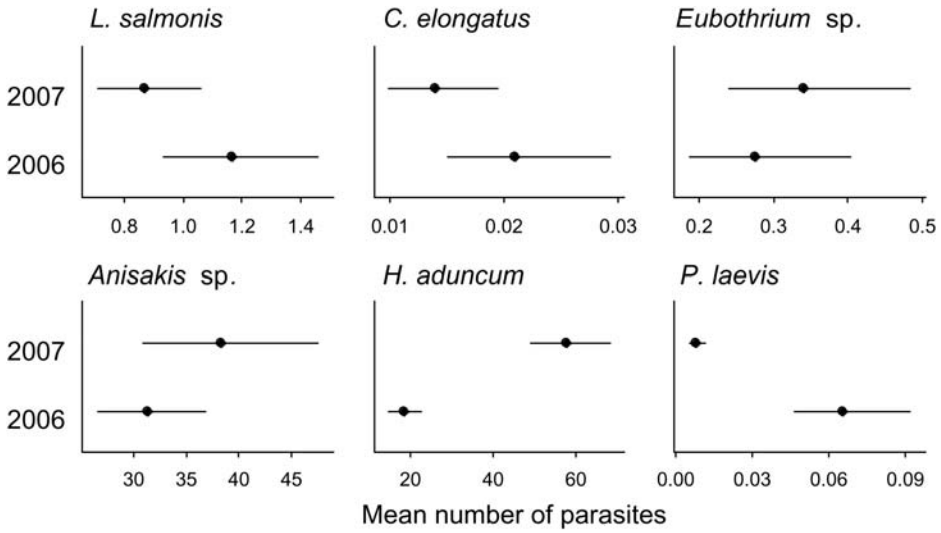

Figure 3. The effect of year on the abundance of each parasite species, with 95% confidence intervals. For easier interpretation, the year effects are centred on the estimated mean abundance in each year at the Upper Forth estuary.

the area effects were common to both years, and the year effects were common to all four areas.

Models investigating the effect of fish length were also considered. Fish length was partially confounded with area (Table 1), which made model fitting and interpretation more difficult. However, fish length had no significant effect on parasite abundance within areas ($p > 0.05$), and it was never selected in preference to area by AIC.

Discussion

The study investigated the presence of viral and bacterial agents and the abundance of metazoan parasites on wild sea trout in Scottish waters over a 3-year period. Most of the fish sampled appeared to be healthy, with no presence of lesions, haemorrhaging, or emaciation, with their organs showing no signs of pathogen infection, although some fish had high loads of both ecto- and endoparasites. No bacterial pathogens were isolated from the fish during this study. One viral pathogen and one viral agent were isolated: one fish was IPNV-positive, and four fish tested positive for aquareovirus. We believe that this is the first report of aquareovirus from sea trout from the east coast of Scotland.

Sea trout from the east coast were typically larger, but younger, than those from the west coast (Table 1). This is consistent with the studies by the Atlantic Salmon Trust (1985), who reported that west coast fish tended to live longer, were slower-growing, and were smaller than east coast fish. There were some differences in sampling time and method between sites, but these are unlikely to have had a large effect on fish size. For example, gillnets, which were used on the west coast, were also used at Stonehaven Bay on the east coast, where fish were similar in size to the other east coast sites. Moreover, water temperatures (obtained retrospectively from marine fisheries agencies for each sampling occasion) in the River Carron were similar to those at the east coast sites, and only a few degrees lower than in the River Annan.

Significantly more *L. salmonis*, *H. aduncum*, and *Anisakis* sp. were found in fish at the east coast sites, and only *P. laevis* was

found in significantly greater numbers at a west coast site. There were small numbers, in some cases single individuals of the endoparasites *Diphyllobothrium* sp. (larvae), cestodes, *Hemiurus* sp., *Hemiurus communis*, *Podocotyle atamon*, *Diplostomum*, *Pseudoterranova* spp., *Capillaria* sp., *Cucullanus cirratus*, *Cucullanus truttae*, *Cystidicoloides ephemeridarum*, *Acanthocephalus anguillae*, *Neoechinorhynchus* sp., and cysts only found in fish from east coast sites. *Bucephalus polymorphus* and *Cryptocotyle lingua* were found in very small numbers only in fish captured at west coast sites. This may suggest that the area from which the fish were captured is an important factor for food source and parasite load and that the North Esk and Upper Forth estuary on the east coast are reservoirs of more enriched parasitic fauna than the River Carron and River Annan on the west. Limited information is available on the habitats at each of these sampling sites. It is also possible that the intermediate and final hosts of the parasites are absent from some sites, particularly on the west coast, which may have influenced the presence of parasites recorded in this study.

The migrations of sea trout cover both marine and freshwater environments, allowing for a wide parasite infection range (Gargan *et al*., 2006). The monogenean parasite *Discocotyle sagittata* infects salmonids in freshwater and has a wide distribution in the northern hemisphere (Williams and Jones, 1994; Rubio-Godoy *et al*., 2003). It has a narrow infection period of ~2 h between hatch and infection of the gills of its host, an event which is temperature-dependent (Gannicott and Tinsley, 1998). *Discocotyle sagittata* was the only monogenean parasite found among 129 parasites from ten locations in a survey of sea trout from the west coast of Ireland (Byrne *et al*., 1999). In the present study, *D. sagittata* was found only on five fish in the North Esk in 2005, perhaps because of the small infection window or the fact that the parasite is found in freshwater and that all the fish were captured in estuarine and tidal areas. Most ectoparasites observed in this study were Copepoda. There were significantly more *L. salmonis* at the east coast sites than at the west coast sites in both 2006 and 2007. Although no differences were observed between fish length and parasite burden within a particular area, fish on the east coast fish were larger than those on the west, and this may have enabled them to harbour greater numbers of lice (Tucker *et al*., 2002). Larger fish may also withstand higher infestation loads of ectoparasites (Tucker *et al*., 2002), which would explain the good overall health of the east coast fish. The numbers of *L. salmonis* differed significantly between sites, with the differences persisting between years. As *L. salmonis* is a major parasite of salmonids, this observation could be significant for farm location.

It is well-documented that wild populations of salmonids carry sea lice (Bruno and Poppe, 1996; Stein *et al*., 2005). It has also been suggested that the numbers of *L. salmonis* on wild fish are generally lower than on farmed fish (Bruno and Poppe, 1996; Dawson *et al*., 1997; Butler, 2002). McVicar (1997) discussed the contribution of farmed fish to the infestation of wild salmonids by *L. salmonis*. However, the east coast sites were in areas devoid of fish farming, whereas the west coast sites were both near salmonid aquaculture. The numbers of lice recorded on the east coast in this study are similar to the numbers on sea trout captured in the sea off East Anglia, England, an area also free of salmonid mariculture (Tingley *et al*., 1997). This would suggest that, because there are no fish farms near east coast sampling sites, they are not the source of the sea lice on the trout from the east coast. Infestation by sea lice is related to population density (McVicar, 1997), so the greater lice numbers on the east coast may be attributable to the greater numbers of salmonids there. However, we have no evidence to support this hypothesis. No *C. elongatus* were found on fish from the River Carron or the River Annan, and only one *C. elongatus* was found on fish from the Upper Forth estuary (in 2007), which suggests that *C. elongatus* has a localized distribution. At all three east coast sites, the numbers of *C. elongatus* were much lower than the numbers of *L. salmonis*, possibly because salmonids are the ultimate host for *L. salmonis*, and *C. elongatus* has a broader host range (Kabata, 1979).

Two species of Cestoda were found in this study: *Eubothrium* sp. and *Diphyllobothrium* spp. In particular, *Eubothrium* sp. were observed at all sites, apart from Stonehaven Bay, over the 3-year study period. Cestodes can be found in both freshwater and seawater, but the marine environment is the most common region for infestation (Fahy, 1980; Scholz *et al*., 2003). The overall abundance and prevalence of cestodes observed in this study were low compared with that documented by Fahy (1980), who recorded large numbers of *Eubothrium* sp. in fish that had only been at sea for a matter of weeks. The abundance of *Eubothrium* sp. decreases as trout become older owing to the stress put on these parasites by successive migrations (Fahy, 1980). Some of the fish captured in our study had been on successive migrations from freshwater to marine environments, which may have contributed to the low numbers recorded.

Several species of nematode were recorded in this study and constituted the majority of the endoparasites recorded. These included *Anisakis* spp., *H. aduncum*, *Hysterothylacium fabri*, *Contraceacum* sp., *Pseudoterranova* spp., *C. cirratus*, *C. truttae*, and *C. ephemeridarum*. The presence of these helminths is not uncommon in sea trout populations nor is the relatively high numbers, also reported by Byrne *et al*. (1999), who found a prevalence of 61.2% of *H. aduncum* from 129 sea trout sampled on the west coast of Ireland.

Three species of Acanthocephala were identified during this study, the most abundant being *P. laevis*, which was only found at the west coast sites. Three strains of *P. laevis* have been reported, two in freshwater and one in seawater (O'Mahony *et al*., 2004). All strains are genetically different: the English strain arose from the cyprinid *Barbus barbus* (barbel), the Irish strain from freshwater salmonids, and a marine strain from the flounder (*Platichthys flesus*; Kennedy, 1984; Evans *et al*., 2001; O'Mahony *et al*., 2004). Salmonids became a substitute host for this parasite when cyprinid numbers declined in Ireland. Evans *et al*. (2001) found intensities of 5–14 worms per fish and a mean intensity of 9.5 worms in rainbow trout (*Oncorhynchus mykiss*) from Northern Ireland. In our study, the greatest abundance of *P. laevis* was 5.53 (s.e. 2.81) at the River Carron in 2006. The mean intensity of *P. laevis* was 7.5 worms, a similar level to that observed by Evans *et al*. (2001).

To conclude, a study of wild sea trout was carried out over a 3-year period at sites around Scotland to assess bacterial, viral, and metazoan parasite status. The sea trout had moderate burdens of both ecto- and endoparasites, but appeared to be in good health. One fish was confirmed as IPNV-positive and four fish were aquareovirus positive, but apart from these findings, no other viral or bacterial pathogen was isolated from the fish in the study. From this survey, there was no evidence of sea trout having higher metazoan-parasite burdens in areas where aquaculture is present than in those devoid of aquaculture activity. The fish captured on the east coast of Scotland were larger and had

higher burdens of both endo- and ectoparasites, which suggests that the area may have a more enriched range of parasitic fauna than the west coast of Scotland.

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